A Histologic Evaluation of Circumferential Filing Versus Reaming in Canal Debridement

Terry Lee Kippa
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A HISTOLOGIC EVALUATION OF CIRCUMFERENTIAL FILING VERSUS REAMING IN CANAL DEBRIDEMENT

BY
Terry L. Kippa

A Thesis Submitted to the Faculty of the Graduate School of Loyola University of Chicago in Partial Fulfillment of the Requirements for the Degree of Master of Science
May 1981
DEDICATION

To Virginia, my wife, who has freely given me her love and support, and to Shelly and Jeff who have been understanding beyond their years.
ACKNOWLEDGMENTS

To Dr. Franklin Weine, my committee chairman and teacher, I extend my sincere gratitude and respect for not only his professional guidance, but also for his friendship and insights to personal living.

To Dr. Gary Taylor, my friend and advisor, I thank him for his contribution to this thesis and my overall endodontic education.

To Dr. Hal McReynolds, I thank him for his friendship and assistance with the histologic portion of this study.

To Dr. Scott Shellhammer and Dr. Lance Crawford, my friends and fellow students, I extend my appreciation for their time spent in helping me to complete this thesis.
VITA

The author, Terry Lee Kippa, is the son of Herbert A. Kippa and Ethel (Larson) Kippa. He was born on July 3, 1945 in Oshkosh, Wisconsin.

His elementary and secondary education were obtained in the public schools of Oshkosh, Wisconsin, where he graduated from high school in 1963.

A Bachelor of Science in Civil Engineering was earned at the University of Wisconsin in Madison in June 1967. While attending the University of Wisconsin he was selected for membership in Chi Epsilon National Honorary Civil Engineering Fraternity and Tau Beta Pi National Honorary Engineering Society.

In October 1967, he entered the United States Navy and was commissioned a line officer in January 1968. He served in the Navy until September 1969.

After one year of pre-dental study at the University of Rhode Island, he entered the University of Iowa School of Dentistry. In August 1972 he commenced active duty in the U.S. Navy Dental Corps, completing dental school on a Navy scholarship and receiving the degree of Doctor of Dental Surgery in May 1974. While attending dental school he was elected a member of Omicron Kappa Upsilon.

In July 1974 he began a general practice residency at the Naval Hospital, Camp Pendleton, California. Upon completion of the residency,
he was transferred to Pearl Harbor, Hawaii where he served as a general dentist until June 1979.

The author's wife is Virginia L., and their children are Michelle Anne and Jeffrey Patrick.
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CHAPTER I

INTRODUCTION

Endodontics has evolved from a field where practitioners attempted to remove from a patient's tooth some mysterious cause for their toothache to a currently sophisticated specialty of dentistry that enjoys a 95% success rate. Root canal therapy is better understood and more accepted today by both the dental profession and general public than at any other time in history. Whereas endodontic treatment was once considered a hazard to the patient's general health, it is now recognized as a safe and reliable means of retaining teeth in a functional state that at one time would have been doomed to extraction.

In the first few pages that follow, a brief historical background of the practice of endodontics will be given. This will show the progression of treatment to the present day emphasis on canal preparation. This historical background will be followed by a more detailed review of the literature on canal preparation.

It will be seen from the literature that there are a variety of techniques for canal preparation. Although there are strong advocates of each of the methods, no one technique has proven to be vastly superior to the others with regard to canal debridement. Furthermore, the literature shows that no method of preparation has been successful in thoroughly cleansing the critically important apical portion of the canals studied.
It is apparent then that further investigation into the cleansing of canals in endodontic treatment is warranted. Therefore, it is the purpose of this study to evaluate histologically two techniques of canal preparation. These techniques will be compared as to their ability to cleanse the apical 4 mm of the canal.
CHAPTER II

LITERATURE REVIEW

A. HISTORICAL BACKGROUND

Throughout history there have been many methods of treating teeth which required endodontic therapy. The earliest and most basic form of therapy was extraction. There are, however, very early records of man attempting to relieve toothaches by treating the pulp rather than removing the tooth. In the later Middle Ages, French anatomist Ambrose Pare (1517-1592) stated, "Toothache is, of all others, the most atrocious pain that can torment a man, being followed by death. To combat this one must recourse to cauterization." In cauterization, he explained, "One burns the nerve, thus rendering it incapable of again feeling or causing pain."

The use of instruments made specifically for total pulp removal appears to have surfaced in the mid 1800's. In 1838 Edward Maynard made barbed broaches from the untempered steel of watch springs filed down to the fineness of horse hair which were barbed on one side. Maynard also made reamers from piano wire and filed them to the desired shape.

Probably due to the lack of readily available endodontic instruments, dentists attempted to clean these canals by other means. In 1883 the process of "knocking out the pulp" was described by Mills. The procedure involved tapping a pointed orangewood stick that had been dipped in carbolic acid into the canal. The wood was left there for a minute and then pulled
out with the pulp coming with it. Although some dentists claimed this to be a relatively painless operation, one patient stated that "it seemed that a broom handle had been thrust up through his head." Schreier, 1893, introduced a combination of sodium and potassium for removing pulp tissue. In 1894, Callahan recommended sulfuric acid as an aid in opening and cleaning small and tortuous canals. In 1923, Johnston also described the use of sulfuric acid for widening and shaping small curved canals. Although these techniques were crude and not based on results of sound scientific study, they do show the concern of the dentist to clean the canal thoroughly.

In the early 1900's bacteria were implicated as etiologic agents of pulp disease. This finding was followed by Hunter's classic report to the Faculty of Medicine of McGill University which warned that oral sepsis and infection could cause many systemic diseases. The principle of what Hunter called oral sepsis was that organisms from diseased teeth would be spread by blood and lymphatic vessels throughout the body and result in focal infections. This theory resulted in the condemnation of all pulpless and pulpally involved teeth and their wholesale extraction. This philosophy continued for many years and was supported by many, what later proved to be erroneous, bacteriologic studies.

Coolidge, in 1932, wrote, "That the tooth of a young person should be extracted just because the pulp has become exposed is one of the worst blots on the escutcheon of dental practice in history." He also stated that, "The possibility of saving the tooth whose pulp has undergone putrefaction depends on control of the infection, mechanical cleansing of
the canal and disinfection of the dentin and inaccessible canals followed 9 by complete closing of the apical foramen."

Fish and MacLean in their study negated the claims that the root surfaces of pulpally involved teeth were infected with micro-organisms. They showed that organisms cultured from the root apices of extracted teeth or from the bloodstream after extraction had been pumped into the vessels from the gingival sulcus during extraction.

These results gave support to dental practitioners who felt that teeth could be saved through conservative endodontic procedures. However, in order to justify their conservative position to the advocates of the focal infection theory and extraction, their goal was to attain a sterile canal. This led to the use of various intracanal medicaments and irrigants, different techniques of mechanical preparation and to culturing. The culture was used to prove that a sterile canal had been attained and the tooth would no longer serve as a focus of infection.

There has been much discussion in the endodontic literature as to the best irrigant, the best intracanal medicament or whether medicaments are necessary at all. Also the importance of these facets of treatment relative to the mechanical debridement has received much attention.

Many of the first endodontists were also pharmacists and they tended to place the major emphasis on drug therapy in the root canal. For years the endodontic literature was filled with dissertations on the role of intracanal medications in rendering root canals sterile.

Cresote and phenol were introduced for use as canal medicaments in the early 1800's and have been used in various combinations since that
time. Formocresol became prominent in endodontic therapy following its introduction by Buckley in 1904. Antibiotics and anti-fungal drugs are still used within the canal by some. In 1951, Grossman introduced his PBSC paste which contained penicillin, bacitracin, streptomycin and caprylate sodium. There were other drugs used and many were very caustic and irritating to the periapical tissues.

Studies such as those by Hedman and Shovelton showed that periapical lesions were either sterile to begin with or could be rendered sterile by thorough cleansing of the canal. These studies as well as one by Engstrom and Frostell have shown that it is not necessary to have bacteria either in the canal or in the periapical tissues in order to have periapical pathology. After such findings it became clear that some of the painful sequelae of endodontic treatment were not caused by infection but by overly strong drugs used within the canal. Rothschild agreed that potent and destructive medicaments do great harm to normal tissues. The situation may be summed up by stating that of prime importance is the removal of debris which nurtures bacteria rather than attempting to sterilize it in situ. No amount of medication will disinfect an unclean canal. The realization that microorganisms and their substrates should be removed instead of being sterilized within the root canal is one of the major advances in endodontic practice. This sentiment towards placing less importance on medicaments and more on debridement is felt by many other endodontists. Bhaskar showed in a study on dogs' teeth that root canal debridement and occlusal seal alone apparently stopped the growth of apical lesions. Weine has noted this same effect
in humans. As a result of this shift in thinking, the use of an irrigant and the search for the best irrigant to be used received more emphasis in the preparation of the canal.

In Coolidge's article he recommended the use of "chlorine solutions" in irrigating canals. In the treatment of wounds in World War I, it had proven to be a powerful and penetrating germicide that did not cause much injury to living tissue. Walker, 1936, wrote that judicious use of a chemical irrigant is helpful in cleansing pulp canals. For this purpose, he recommended double strength chlorinated soda because of its germicidal property and its ability to dissolve organic material.

Grossman and Meiman added further credence to the use of chlorinated solutions when they showed that chlorinated soda is an effective solvent of pulp tissue. They found that it will dissolve pulps of freshly extracted teeth in less than 24 hours and at times in less than one hour. They also stated that the elimination of necrotic pulp tissue from the root canal is important for the ultimate success of the operation.

Contrary to these studies, Baker, et al., reported in a comparison of various irrigating solutions used in preparation of freshly extracted teeth that NaOCl did not show any ability to dissolve pulpal tissue. The removal of debris and microorganisms seemed to be a function of the quantity of irrigating solution rather than of the type of solution used.

Studies were done to evaluate the effectiveness of NaOCl as a bacteriocidal irrigant during canal preparation. Auerbach, in a study involving 60 nonvital teeth, found that 78% of the teeth which had positive initial cultures yielded negative cultures after debridement of the canals
with chlorinated soda as an irrigant.

Stewart in 1955 reported two successive negative cultures in approximately 76% of infected canals after chemomechanical preparation in which 3% hydrogen peroxide and sodium hypochlorite was used.

In 1958 Ingle and Zeldow reported on a study designed to show that a chemical irrigant was a necessary adjunct to mechanical instrumentation in the reduction of bacterial flora of the canal. They instrumented 89 teeth with nonvital pulps with sterile distilled water as an irrigant. Results of their study showed that only 4.6% of infected canals yielded two successive growth-free cultures. These findings show the importance of the antibacterial action of irrigating agents used by Auerbach and Stewart.

Nicholls, 1962, reported on a study that was designed to assess the effect of variation in irrigating agents used during instrumentation upon the bacteriological status of the canal. Comparing alkaline chloramine, \( \text{H}_2\text{O}_2 \) and \( \text{NaOCl} \), and distilled \( \text{H}_2\text{O} \) they also concluded that the reduction in bacterial population is to some extent associated with the antiseptic effect of the irrigants.

Shih, et al., reported that irrigation with full strength (5.2%NaOCl) Clorox does not ensure the lasting sterility of an inoculated canal. They also concluded that a negative culture report after treatment indicates that the bacterial population in the root canal may be highly reduced, not that the canal is sterile.

Unfortunately, the use of NaOCl does not guarantee that the canal is thoroughly debrided. Senia, et al., in 1971 reported on a study that
was designed to evaluate the solvent action of Clorox (5.2% NaOCl) in canals of extracted mandibular molars. They found that full strength Clorox did not appear to be very effective in removing pulp tissue which remained after instrumentation. In their study, there was no significant difference in the cleaning effect of Clorox as compared to normal saline solution at the 1 mm and 3 mm levels from the apex. Neither solution was effective in removing debris left by instrumentation.

This finding was confirmed by Baker, et al., in 1975 when they reported a SEM study on the efficacy of various irrigating solutions including saline, $\text{H}_2\text{O}_2$, $\text{H}_2\text{O}_2$ plus NaOCl, NaOCl, Glyoxide, Glyoxide plus NaOCl, RC Prep, and EDTA. The study indicated that even when teeth were instrumented and irrigated, significant amounts of tissue and debris remained in the prepared root canal system.

Svec and Harrison (1977) compared the cleanliness of canals prepared with NaOCl and hydrogen peroxide to those prepared with normal saline. Although the NaOCl and $\text{H}_2\text{O}_2$ combination was found to be significantly more effective, pulpal and dentinal debris were found in almost every section.

It has become clear that no irrigant or combination of irrigants could completely cleanse a canal of debris. Thus the emphasis in endodontic therapy has shifted from relying on strong intracanal medicaments to cleansing canals with irrigants to its present day stress on the mechanical removal of debris with the aid of an irrigant.

Reports by Walton and Rubin, et al., have reinforced the findings of the studies evaluating irrigants. Their studies on instrumentation techniques both showed that the debris is removed by the mechanical
action of the instruments. In other words, debris remained wherever the instruments did not actually contact and remove it.

This line of thought is confirmed by looking at the causes of endodontic failures. In any endeavor, careful study of one's failures can lead to improvement in techniques. Reports on endodontic failures indicate that an emphasis on thorough canal debridement is definitely indicated. Hatton in 1928 found that teeth that were considered endodontic failures contained a very high percentage of superficially clean roots with much of the pulp tissue still remaining. Wilkinson wrote in 1929 that the fundamental problem in root canal treatment was the complete removal of protein debris and that our failures were due to our inability to effect that removal.

Ingle at the 1961 annual meeting of the AAE, reported on the cause of endodontic failures in over a thousand cases reviewed at the University of Washington Dental School. The greatest single cause of failure was incompletely filled root canals combined with debris-laden root apices.

Seltzer, et al., found that endodontic failures may be caused by local or systemic factors. Among the local factors, poor or inadequate debridement of the root canal was found to have a definite relationship to the failure of endodontic treatment.

Malooley, et al., found in a study on monkeys that when their filling material did not obturate the apical 1/3 of the canal and infected tissue remained lateral to the sealing material, healing of periapical lesions did not ensue. These results emphasized the importance of
properly preparing the apical portion of the canal in order that an apical seal may be obtained with the filling material.

Ingle and Heuer both state that for endodontic therapy to be successful all phases of treatment must be satisfactorily completed. The three phases listed by them are biomechanical preparation, microbial control, and obturation of the canal. As seen in the literature reviewed in the preceding pages, the latter two depend heavily on the first phase. It is generally accepted that biomechanical preparation is the most critical step in this endodontic triad. Grossman states in his textbook, "that adjuvants in the form of irrigants or antiseptics for dissolving pulp tissue fragments or destroying microorganisms must be looked upon as inefficient substitutes for efficient instrumentation rather than efficient substitutes for inefficient instrumentation." Heuer states that success in endodontic therapy is unrelated to the type of intraradicular medication used, to whether bacteriologic controls are employed or what materials or methods are used in filling the root canal, provided that thorough biomechanical preparation and hermetic sealing of the root apex have been met. It is not possible to attain an apical moisture-proof seal unless the space to be filled is carefully prepared to receive the filling material. Rothschild also states that only when instrumentation leaves canal walls clean, hard and free of surface residues is it possible to ensure effective sealing of the canal.

According to Crump, a poorly filled canal casts doubt on the adequacy of canal preparation and failures attributed to poor canal obturation may in fact have resulted from failure to clean and prepare the canal.
properly.

Most recently, Russin, et al., (1980), reported on their study evaluating apical seals obtained with various forms of obturation. They found that most specimens leaked at the 1 mm level due to the fact that they were unclean at that level and difficult if not impossible to seal.

The evidence is overwhelming that canal preparation is the most important phase of endodontic therapy and the basis for successful results. According to Weine, the importance of canal preparation cannot be overemphasized. Healing may be initiated once the irritants to the periapical tissue are removed from the canal.

Because the emphasis in endodontics has shifted away from therapeutics to canal debridement there have been many techniques of instrumentation devised. Each method instituted with the hopes of providing more through debridement.

B. CANAL PREPARATION

Kuttler wrote in 1955 in his classic article on root canal anatomy that one of the main reasons for failure of root canal therapy is lack of knowledge of the anatomy of the pulp cavity. Vertucci reiterated this thought when he stated that successful endodontic treatment demands that the dentist have a thorough knowledge of root canal morphology. The failure to locate and prepare a patent canal will decrease the chances of success significantly. Canal configuration and its endodontic
significance has been extensively reported in the literature. All of these studies demonstrate that canal anatomy is highly variable and complex.

This complexity of the canal systems and the realization of the importance of thorough canal debridement have resulted in the design and manufacture of various endodontic instruments. There are basically three instruments that are used for canal preparation. These are broaches, files, and reamers.

There are two types of broaches: smooth and barbed. The smooth broach is used as the initial instrument to explore the canal. The barbed broach is formed by notching a tapered soft steel blank. This produces sharp barbs which extend outward from the shaft. The instrument is used for gross removal of debris from a canal. This includes pulp tissue, food, paper points, and cotton pellets. It is a weak instrument and can be easily broken if it is forced apically after its initial contact with the walls of the canal and then twisted.

Files are manufactured by twisting square or triangular blanks. This produces a series of cutting edges and flutes which function in the removal of hard tissue during canal preparation. Files manufactured in this manner are called "K" type files for the Kerr Manufacturing Company that first manufactured them. Another type of file, the Hedstrom file, is manufactured by cutting triangular segments out of a round blank.

The third type of instrument is the reamer. They are manufactured in the same way as files except that they are not twisted as tightly and therefore have fewer flutes per millimeter than the files.
The design of different instruments dictates the manner in which they can be used most efficiently. Both reamers and "K" type files can be used with either a reaming or filing motion. Oliet and Sorin found that instruments formed from triangular blanks cut more efficiently than those made by twisting a square blank.

Reaming motion involves the placement of the instrument apically until a small amount of binding is felt. The instrument is then rotated clockwise a certain amount and withdrawn. The clockwise rotation causes the instrument to cut into the canal walls and the dentin engaged is removed as the instrument is withdrawn.

Filing motion or rasping is done by scraping the walls of the canal with the instrument on the withdrawal stroke. There is no use of rotation in this form of instrumentation. The file is more efficient than the reamer in this type of motion because its cutting edges are more perpendicular to the long axis of the instrument than those of a reamer.

Circumferential filing is a method of filing whereby the file is directed against the walls of a canal in a sequential manner until all walls have been planed.

Studies such as Vessey's have shown that the method of using an instrument is more important than the type of instrument in determining its effect on canal preparation.

The Hedstrom file is very sharp and can remove dentin rapidly. This instrument can be used only with a filing motion. The file is weak at the points where metal has been removed and is prone to breakage if it is rotated while bound in dentin.
Up to this point the instruments referred to have been hand operated; however, they all have engine driven counterparts, which are made to be operated in special handpieces designed to provide a reciprocating motion similar to reaming. Two representative handpieces of this type are the Giromatic and the Racer. The Giromatic is designed to rotate an instrument $\frac{1}{4}$ turn in alternating directions, while the operator moves the handpiece in a push-pull motion, thus removing dentin. The Racer handpiece differs from the Giromatic by supplementing oscillating movement with a short up-and-down stroke similar to a combined reaming and filing action.

Prior to 1958 endodontic instruments were not standardized in size or shape. The instruments were numbered from one to twelve. Each manufacturer had his own specifications, and therefore, a size number 3 file made by one company may not have the same taper, length, or diameter of a number 3 file manufactured by another company. A great step forward for the field of endodontics occurred in 1958 when the Second International Conference on Endodontics, at the suggestion of Ingle and Levine, adopted specifications for a system of standardized instruments. These specifications established the following:

1. A formula for the diameter and taper in each size instrument
2. A formula for a graduated increment in size from one instrument to the next
3. A new instrument numbering system based on instrument diameter
Although root canal instruments and filling materials have been standardized, there still remains much controversy as to which technique of utilizing the instruments is the best. Grossman states that, "The object of biomechanical preparation is to cleanse the pulp chamber and root canals of pulp remnants, foreign debris, infected or softened dentin in the pulp chamber or on the canal surface, to remove obstructions; to enlarge the canal so as to receive the maximum amount of medicament or antibiotic; to smooth the canal wall, and to prepare the canal walls so as to facilitate obturation." These objectives are for the most part agreed upon by the authors of the major endodontic textbooks in the country. Despite the basic agreement on the goals of canal preparation there still is much discussion and controversy as to which is the best method of using these instruments to achieve the above objectives. Each of the four major textbooks on clinical endodontics advocates the use of a slightly different technique of canal preparation.

Grossman, in his book, lists the following twelve general rules governing biomechanical instrumentation:

1. Direct access should be obtained along straight lines.
2. Smooth instruments should precede barbed or rough instruments.
3. The length of the tooth should be accurately determined.
4. Instruments should be used in sequence of sized.
5. Reamers should be given only $\frac{1}{4}$ to $\frac{1}{2}$ turn at a time.
6. Files should be used with a pull stroke.
7. Reamers and files should be fitted with instrument stops.
8. The canal should be enlarged at least 3 sizes greater than its original diameter.
9. A reamer or file should not be forced if it binds.
10. All instrumentation should be done in a wet canal.
11. Debris should not be forced through the apical foramen.
12. Instruments should be confined to the root canal so as not to traumatize periapical tissue.

Grossman advocates use of the "step-back" or serial preparation as described in detail by Schilder.

Ingle draws an analogy between G.V. Black's principles for cavity preparation in operative dentistry to preparation of a root canal system. As in operative dentistry, the final restoration is rarely better than the initial cavity preparation. According to the author, principles IV, V, and VI may be applied to endodontic therapy.

Principle IV - toilet the cavity - This step involves meticulous cleansing of the walls of the root canal until they are glassy smooth and the apical 1/3 is perfectly clean.
Principle V - retention form - The apical 1/3 of the preparation must provide 2 to 5 mm of nearly parallel walls to ensure the firm seating of the primary filling point. The small amount of taper provides retention of the point, the fit of which usually can be measured by the "tug back." Coronally, from the area of retention, the cavity walls are deliberately flared, in a good many preparations, during toilet of the cavity. The final 2 to 3 mm of the preparation is most crucial and calls for meticulous care in its preparation. This is where sealing against future leakage or percolation into the canal takes place.

Principle VI - resistance form - In order to successfully develop resistance form, the operator must maintain the integrity of the natural constriction of the apical foramen. Kuttler has shown that the narrowest waist of the apical foramen lies at the dentinocemental junction.

According to Ingle it is a major goal of canal preparation to develop a round, tapered apical seat to receive the preformed filling materials. Depending on the shape and size of the canal system there is an optimal method of cleaning and shaping. Different techniques are
described for preparing a Class I or Class II root canal system. A Class I root canal system is described as an uncomplicated, mature root canal that is either straight or gradually curved and has a constriction at the foramen. A Class II system is a complicated mature root canal that is severely curved or dilacerated or with an apical bifurcation, but all with an apical constriction.

The following technique for preparing a Class I canal is given:

For this type of canal Ingle recommends that the preparation be done by reaming action at working length until clean white dentin chips are being removed by the instrument. The canals that sometimes may be enlarged entirely by reaming action are the two canals of a maxillary first premolar and the small canals of molars, particularly in older patients in whom secondary dentin has narrowed the lumen of the canals.

For canals that cannot be prepared entirely by reaming action, filing action must be used in the coronal two-thirds. This area is perimeter (circumferential) filed to solid "white" dentin. During this phase of preparation the instrument stop should be moved up 3 to 4 mm to prevent the file from invading the apical third which has been prepared into the round, slightly tapered form to receive the initial filling material. Recapitulation should be carried out after each instrument is used in a filing action to ensure that the apical portion of the canal is not clogged by debris. Recapitulation is the follow-up cleaning action of returning full-length with the initial instrument to remove dentinal debris that forms as the body of the canal is being shaped with larger instruments.
In most Class I canals with large tapered preparations, gutta-percha will be used as the filling material. However, single silver-point fillings can be used in cases where narrow-lumen canals have been reamed to the round tapered shape throughout.

Preparation of curved (Class II) canals is as follows:

The author gives general guidelines for preparation of curved canals and then divides preparation techniques into those for silver points and those for gutta-percha fillings.

The operator should always use a curved instrument in a curved canal. Ingle states that using a curved instrument "per se" will not necessarily ensure success; however, he categorically states that straight instruments used in curved canals will ensure failure.

Also, when rotating small instruments in curved canals, they should never be rotated more than half a turn because more tension leads to breakage.

Silver points are recommended for use over gutta-percha in fine curved canals if the dentist believes that the apical portion of the preparation is perfectly round. The preparation for silver points is somewhat faster than that for gutta-percha; however, the completeness of obturation rather than the speed of the procedure should be the deciding factor in selection of the technique.

The silver point preparation is done by reaming. Starting with a No. 10 or 15 instrument tight in the canal one advances the sized upward, but rarely past No. 25 or 30. At this point, clean white dentin is removed with each cutting and the round tapered preparation is ready
for filling.

For gutta-percha preparation of Class II canals, a step-back method of cavity is prepared. The technique has been described as a telescopic preparation by Martin. This is a variation of the flared preparations described by Weine and Schilder. The objective of these preparations is to permit the proper resistance and retention form to be attained in curved canals while minimizing the risk of apical perforation. The basic technique is as follows:

1. The apical portion of the canal is enlarged by reaming action to a No. 25 to 35 instrument. The greater the apical curve the smaller the instrument used.

2. At this point each successively larger instrument is used with reaming action 1 mm short of the previous instrument.

3. This step-back instrumentation is continued until the entire curved portion of the canal has been prepared.

4. Recapitulation is carried out frequently during the step-back phase of preparation.

Schilder advocates preparation designed to be used with vertical condensation of warm gutta-percha as the filling technique. He prefers to use the term "cleaning and shaping" of root canals as opposed to root canal instrumentation, enlargement, etc. "Cleaning" refers to the removal
of all organic substrates and related microorganisms from root canals. "Shaping" refers to the development of a funnel shape of decreasing diameters to be apex in each root canal to facilitate the placement of a permanent three-dimensional filling.

The initial preparation is aimed toward establishing patency in the apical third of the canal. The same principles and sequences of instrumentation apply to all canals in both anterior and posterior teeth.

The procedure to be used is as follows:

The working length is established at the radiographic apex which in most instances is past the apical foramen. All files used apically must be precurved and advanced to the foramen with a probing action. At working length, the file should be stroked repeatedly in a 0.5 to 2 mm amplitude, in and out along the path of the curve. This will minimize apical ripping and fluting associated with a strong lateral filing motion. Files are not to be given quarter turn bites into dentin or pulled forcibly with lateral pressure along all walls. After the No. 10 file fits freely, proceed to a No. 15 file. Proceed in the same manner with the No. 15 file until it will pass freely to the apical foramen.

Next a precurved No. 15 reamer is placed to working length and rotated 180° and withdrawn in order to assist in the removal of dentin mud formed by the filing with the No. 10 and 15 file. This sequence is then repeated with a No. 20 file followed by a No. 20 reamer. It is important to remember that in this technique reamers are used to remove the dentin mud and not to cut around curves.

In a fine canal this concludes the initial preparation of the apical
portion of the canal. In larger canals, the preparation could continue in the same manner to larger size instruments. The apical portion should now be patent, free of debris, and undeflected from its original path.

When instrumentation reaches the point that larger instruments will not proceed easily to the apex, one should proceed to the preparation of the body of the canal.

All further preparation is done with reamers and Gates-Glidden drills with files no longer being used. Continuing with the case above, a No. 25 reamer is introduced into the canal until it makes contact with the walls. It is turned $180^\circ$ and withdrawn with no attempt to force the reamer apically beyond the depth of the first contact. A No. 30 and 35 reamer are used in exactly the same manner.

Now a Gates-Glidden drill is used in the cervical region of the canal to blend the prepared canal into the access cavity.

In this technique the Gates-Glidden drills are not intended to be used as end cutters but only the widest circumference of the bur should make contact with the dentin walls. Usually, two consecutive size drills are used. Typically, the initial use is with a No. 2 drill followed at a later stage in the preparation with a No. 3 drill. After use of the first Gates-Glidden drill, the working length should be remeasured and the first recapitualtion completed.

Recapitulation is "the sequential reentry and reuse of previously employed instruments within the root canal." It starts with the repositioning of the last reamer at the foramen and the serial reintroduction of every subsequent instrument into the body of the canal.
Continuing the illustrative case from above, the No. 20 reamer is reintroduced to working length and a new measurement film taken. Next, the series of reamers, No. 25 to 35, are used in the same manner as previously stated. Each instrument will penetrate deeper than it did before because of the elimination of cervical and middle third constrictions. Larger size reamers may now be used in a similar manner. At this point the second Gates-Glidden drill may be used.

Recapitulation may be repeated as often as desired in order to prepare the apical region to the desired size. Once the cleaning and shaping of the canal have been completed, a final working length film should be taken prior to obturation.

The method of canal preparation recommended by Weine is based on the following rules:

1. Preparation must enlarge the canal while retaining the preoperative shape. If the preparation does not maintain the original canal course, the apical foramen will not be part of the preparation and there is no way to attain an apical seal. All instruments must be precurved and the use of reaming action and chelates must be minimal.

2. Once the working length of the canal is determined, all instruments must be kept within the confines of the canal. This necessitates the use of some form of stop on each instrument. It is important for the preparation to end in solid dentin. This
apical end of the preparation acts as a matrix against which the canal filling material can be packed. This prepared area is called the apical dentin matrix.

3. Instruments must be used in sequential order without skipping sizes. The use of reaming action or forcing to get an instrument to working length may cause it to deviate from the true canal.

4. Instruments must be used extravagantly, particularly in the smaller sizes. Sizes 8 and 10 should be discarded after one appointment in order to avoid breakage.

5. Canals must be prepared in a wet environment. Gly-Oxide is recommended for use in fine canals to be followed by NaOCl as the canal is enlarged to a size 20 or larger.

Weine also advocates use of a flare or step preparation. This type of preparation provides room for pluggers and spreaders to reach the apical few millimeters of the canal to allow for adequate condensation of gutta-percha. Another important feature of the flared preparation is that only the smaller more flexible instruments are used at full working length. Thus, by not using the stiffer larger instruments near the apex the chances of deviating from the original canal shape are decreased.

Attempting to use too large an instrument at full working length
can also result in ledge formation.

A typical flare or step preparation is completed in the following manner:

1. The largest file that will go to full working length is used until it is quite loose.
2. The canal is enlarged three full sizes larger than the initial instrument. This third larger instrument is called the master apical file (MAF) and is the largest instrument used at full working length.
3. The flaring procedure is initiated by using the next size instrument 1 mm short of the full working length. This is followed by use of the MAF at full working length.
4. A file two sizes larger than the MAF is used 2 mm short of working length and is followed by use of the MAF at the full working length.
5. A file three sizes larger than the MAF is used 3 mm short of the working length and is followed by use of the MAF again at full working length.

Canals may be sclerotic or severely curved and may require the use of additional procedures to facilitate safe canal preparation.

As stated earlier, all instruments must be precurved. Canal walls may have irregularities that obstruct the passage of a file to working length. Any rotation of a straight instrument will drive the tip of the
file into the canal wall and result in ledge formation.

In some fine curved canals, the increase in diameter of 0.05 mm when proceeding from one standard instrument to the next may be too great. The larger instrument may not passively reach the working length. In these cases, incremental instrumentation should be employed. This involved cutting off the tip of the instrument which creates an intermediate size. Because of the consistent taper of standardized instruments, removing 1 mm of length will increase the diameter of the tip by approximately 0.02 mm. Thus a size 10 file becomes a size 12.

Also, in curved canals there is a need for remeasurement of working length during preparation. This is due to the gradual straightening of the canal by the files. It is recommended that a new working length film should be taken for every increase of three instrument sizes.

With regard to the use of engine-driven instruments for canal preparation, Weine states that he is not in favor of their use, particularly at full working length. This is because they have no apparent time advantage and they cause large deviations from the original canal shape. Gates-Glidden burs and Peeso reamers may be used with care in the cervical third of a canal to aid flaring. They must be used to cut only on the withdrawal motion and at very slow speeds.

These methods of preparation and slight variations of them have been evaluated in numerous studies. The standardizing of root canal instruments and filling materials initially led to attempts by dentists to prepare root canals round. In that way, it was theorized, a single standardized silver or gutta-percha point would completely obturate the
apical portion of the canal. Therefore, many of the earlier studies were designed to evaluate the roundness of prepared canals.

Haga (1968), who instrumented 161 canals in 131 teeth with "K" type files and reaming action, concluded that it's difficult to prepare a perfectly round preparation at the 2 mm level from the apex.

Vessey (1969) examined the possibility that the type of instrument used would determine the final shape of the canal. He compared files to reamers and filing action to reaming action on 33 lower incisors. After preparation was completed, the teeth were examined at 1 mm intervals starting 1 mm short of the working length and continuing up to 4 mm short of the working length. He concluded that a rounder preparation could be attained by using reaming action and it made no difference whether a file or reamer was used. Therefore, how an instrument is used rather than the type of instrument is more important in determining the final shape of the canal.

Schneider (1971) reported on a study designed to determine the frequency with which round preparations could be produced by hand instrumentation in the apical 1/3 of straight and curved canals. He found that straight canals were much more readily prepared round than were curved canals. At the 1 mm level, only 37% of the curved canals were round.

Davis, et al., studied the postdebridement canal anatomy of 217 teeth. They found that the prepared canal was very dissimilar to the instruments used to prepare them, especially in the apical third.

In 1974, Harty and Stock reported the results of a study in which the mesial canals of extracted mandibular molars were prepared with
either a file in a reciprocating handpiece or a hand-held file. Of the total of 82 canals prepared, not one was round in cross-section in the apical third of the canal.

The purpose of Jungman's, et al., study was to use four common techniques of root canal instrumentation and evaluate the final shape of the canal by measuring the canals widest and narrowest diameters at the 1½, 3, 4½ and 6 mm levels from the apex. 150 mandibular molars were divided into three groups as follows:

Group 1 - Control, received no instrumentation

Group 2 - 1 of the mesial canals was prepared with "K" type files and filing action and the other canal was prepared with a reamer and reaming action.

Group 3 - 1 of the mesial canals was prepared with "K" type files and reaming action and the other mesial canal was prepared with the Giromatic handpiece using Giromatic reamers.

Instrumentation was considered complete when each canal was enlarged 2 instrument sizes beyond the first size that was necessary to cut dentin in the apical part of the canal.

They concluded that no technique of instrumentation will predictably produce a round preparation in the apical portion. Reaming action with a K-type file produced the roundest preparation. The least round
preparation was produced by using filing action with a K-type file. These findings were in agreement with those of Vessey.

The above studies on the shape of the prepared canal all examined cross-sectional specimens. Other investigators have looked at prepared canals in longitudinal views.

Gutierrez and Garcia (1968) conducted a study designed to determine the shape of canals after enlargement and detect any difference between work done with files and reamers vs reamers alone. Thirty lower incisors and thirty canines were enlarged with files and reamers. Another thirty lower incisors and thirty canines were instrumented with just reamers. At the completion of preparation the teeth were split longitudinally in a bucco-lingual direction. They found that several of the prepared canals had a constriction near the junction of the middle and apical thirds and then widened again near the apical foramen. These root canals had an hourglass shape. They also found no noticeable difference in the preparations whether reamers were used alone or in conjunction with files.

Weine, Kelly and Lio used a system of clear casting resin blocks which contained simulated curved canals in order to demonstrate the effects of preparation procedures on canal shape. The canals were prepared by a variety of techniques and operators. In spite of this fact, all of the final preparations showed the following three characteristics:

1. The same "hourglass" appearance described by Gutierrez and Garcia was present. Weine
called the constricted area the "elbow."

2. Whether the files were precurved or straight, they tended to straighten within the canal.

3. Each succeeding file went further away from the inner portion of the curve between the elbow and the tip of the preparation.

If a canal were prepared past the apical foramen this migration of successive instruments away from the inside of the curve gave the foramen a teardrop shape. Weine called this the apical "zip." In order to avoid this "zipping" phenomena, Weine recommended removing the flutes of the file on the outside of the curve near the tip.

The results of these studies led to the increased popularity of gutta-percha as a filling material and a sharp decrease in the use of silver points. It was reasoned that since the prepared canals were not round, a more adaptable material was needed to fill the prepared shape of the canal. The use of gutta-percha instead of the much stiffer silver points required a different type of preparation to receive the filling material. The stiff silver points could be forced into narrow canals whereas the more flexible gutta-percha points require a larger size to attain the stiffness required to reach the tip of the preparation. Until recently, canals were therefore prepared to excessively large sizes just so the gutta-percha used would be large and stiff enough to reach the apex. This type of instrumentation caused marked changes in canal shape in curved canals due to the stiffness of the larger instrument sizes.
Mullins reported a study comparing three methods of canal instrumentation of curved canals with regard to maintaining the original shape of the canal and preventing displacement of the apical foramen. The first method he used prepared the canal to a size 25 or 30 at the working length and then used serial preparation with recapitulation in 1 mm increments from working length up to a No. 40 or 45 file. The second method used serial preparation to routinely instrument fine molar canals to a No. 40 file at working length. The last method tested also prepared to working length with a No. 40 file. This preparation is unique in that it involves grooving of the canal away from the curve in order to reduce the total curvature of the canal.

Using a modified Schneider's method of determining canal curvature, the original degree of curvature was determined for each canal. These measurements were compared to the corresponding measurements after the preparations were completed. The results indicated there was a significant rise in the incidence of producing a "zip" when the canals were instrumented routinely to a size 40 file. Therefore with respect to the points considered here, it would appear better to limit apical preparation of these fine curved canals to a size 25 or 30 file.

In a closely related study Miller evaluated three methods of canal instrumentation of curved canals with regard to their abilities to maintain the original pathway of the canal. This study was done on extracted maxillary incisors and the degree of curvature was determined by Schneider's method. Teeth were separated into three groups based on their degree of curvature as follows: straight - less than 10°; moderate - 10
to 20°; severe - greater than 20°.

The three methods of instrumentation were as follows:

Method I - A ¼ turn-pull method of reaming was used to enlarge the canal to a No. 40 at working length.

Method II - The canal was prepared to a No. 25 file at working length using only a filing motion. For succeeding instruments a file and then a same size reamer was used at working length until the canal was enlarged to a No. 40. The body of the canal was then flared using reamers only.

Method III - The canal was prepared to working length with a filing motion to an instrument two sizes larger than the first file that bound at working length. The canal was then flared.

The final preparations were evaluated as to whether the original canal shape was maintained, whether a new canal was formed (deviation from original) or whether the canal was ledged short of working length.

The results indicated that methods I and II were very similar. Respectively 61% and 69% of all curved canals had a new canal formed or were ledged. If only the severely curved (greater than 20°) canals
were considered, methods I and II showed 100% of new canal formation or ledging. In Method III 17/18 or 94% of the curved canals maintained the original shape of the canal. One severely curved canal was ledged.

Thus, the flared preparation with minimal apical instrumentation was decidedly better in maintaining canal shape. Also, as pointed out by Weine, the flare eliminates the elbow which would restrict the placement and condensation of gutta-percha at the apex. Condensation of gutta-percha to within 1 mm of the working length is extremely critical in attaining an apical seal. It is for these reasons that some form of flared preparation is taught by most dental schools today.

Canal preparation techniques can be evaluated primarily from two different viewpoints. As shown in the previous studies, effect on original canal shape can be used as a criteria. A second standard used to evaluate canal preparation techniques is how thoroughly they debride canals. As the studies on endodontic failures indicated, poor obturation may be the result of poor canal preparation and debridement. The complete obliteration of the canal in the apical area is the ultimate goal of endodontic therapy. Therefore, in addition to meeting the above criteria a canal preparation technique must allow for successful filling of the canal by the method of choice. Another point to be considered is the amount of time a technique requires. Although this point should be of secondary importance to the above listed criteria it receives considerable attention from the practicing dentist. According to Frank, "the search for armentarium to minimize time spent at the chair never ends." This desire for a faster method of root canal therapy is what gave birth to
the Giromatic and other related handpieces.

Several studies have been done specifically to evaluate canal debridement. Other studies designed to investigate canal shape or irrigating effects have incidentally provided information about the cleanliness of prepared canals. Key studies concerning canal debridement will now be reviewed. Hand instrument studies will be followed by a brief review of mechanical handpiece studies.

Hatton, on examining prepared teeth, found many with much of the pulp tissue remaining. He wrote, "All pulp tissue cannot be removed until the shape, course, and diameter of the canals are modified by filing and curettment."

Haga used K-type standardized files to enlarge the canals in his study. Enlargement of the canals was stopped two sizes larger than the first instrument that started to "bite" 5 to 6 mm from the apex. This was for canals less than a size 35 instrument. Canals larger than this were prepared three sizes larger. All types of extracted human teeth were used except third molars. The method of enlargement was to insert the file into the root canal until there was a definite stop and then the instrument was given a quarter of a turn and withdrawn. This reaming action was continued until the file reached the desired working length. Water was used as a irrigant during all preparation.

The roots were sectioned perpendicular to the long axis of the canal so that the preparation could be examined 2 mm and 6 mm from the tip of the root. These two particular levels were chosen since preparation of
the root canals for filling is aimed at the apical third of the root.

The results showed that in many of the canals the instrument made a cut only on three walls, leaving a void in the fourth wall. He considered a preparation inadequate when voids and irregularities were not removed. The percentage of inadequate preparations was surprisingly high in all teeth except maxillary central incisors. Inadequate preparations were found in 82% of mesiobuccal canals of maxillary molars, 81% of mesial canals of mandibular molars, and 79% and 75% in mandibular incisors and bicuspids respectively.

Among his conclusions, Haga stated that one cannot assume that an adequate preparation has been cut even though clinically the preparation may "feel" adequate and "white dentin chips" are being removed by the instrument. More importantly he concluded that more attention should be paid to the preparation of root canals.

The Gutierrez and Garcia study, referred to earlier, prepared lower incisors to a size No. 6 and the canines to a size No. 100 instrument. The exact technique of instrument manipulation was not given. The teeth were irrigated with either saline solution, sodium hypochlorite or EDTA solution. Their results showed that 78.3% of the incisors and 85% of the canines (upper or lower) had canal walls which it was not feasible to negotiate because of buccal, lingual, or mixed finlike prolongations. In many cases, even those without prolongations, the instruments left a pathway through the geometric center of the canal, cutting off only a minute part of the dentin walls.

The authors stated that although it was not a main objective of
their article they felt it was important to call attention to these pro-
longations and their role in the accumulation of pulpal debris and in the
interference with a tight root canal obturation. They also concluded
that even though all the teeth were enlarged to relatively very large
sizes, a high percentage of the canals were not adequately debrided.

Senia, et al., instrumented the mesial canals of human mandibular
molars to a size No. 30 reamer and filed the walls with a No. 25 file.
Each root was cross-sectioned at 1 mm, 3 mm and 5 mm from the apex.
They found that the flutes and canal wall deviations reported by Haga
and Gutierrez and Garcia were present. They also concluded that the mech-
anical preparation by standard techniques was inadequate in most cases
and the canals were not adequately debrided and cleaned in the apical
5 mm.

Davis, et al., (1972) prepared the 217 teeth used in their study
"with standard endodontic instruments." During instrumentation 2.5%
NaOCl solution was used as an irrigant. Canals were prepared until the
operator thought that the canals were thoroughly debrided, the walls were
smooth, and the preparation had reached a point where any standard filling
method could be employed. The prepared canals were filled with a syringe
type of silicone impression material. The teeth were then dissolved
leaving the models of the canals.

Finlike extensions of the main canal were also found in this study.
They were most often seen in mandibular incisors, mesio-buccal roots of
maxillary molars, and in maxillary second premolars. Instrument markings
were seen in the models, especially if the canal was curved. These
markings represented the scratch marks of the instruments as they were worked during canal preparation. In many of the curved teeth, these markings were seen on only one wall, whereas no markings could be seen on the opposite wall. As much as half of the surface area of the canal is never touched by the instruments because of the tremendous anatomic variations. The fins, irregularities lateral canals, and accessory canals may be filled with necrotic tissue and/or bacteria.

The authors concluded by posing questions as to how this material can be removed, how the irregularities can be filled, or whether it is necessary to fill them. They felt that further work needed to be done in this area.

Baker, et al., (1975), in their study on irrigating solutions, instrumented the teeth initially with reamers and then with files to complete the preparation. Instrumentation was continued until clean, white shavings were obtained and the canal walls felt smooth to the touch when probed with an instrument. The prepared teeth were then split longitudinally and examined with the scanning electron microscope.

As shown in earlier studies, generally one side of each canal appeared more thoroughly debrided and cleaner than the opposite side. It was observed in many specimens that one side of the canal was well debrided while the opposite side of the same canal often showed significant amounts of debris and remaining pulpal elements.

Coffae and Brilliant compared serial preparation to nonserial preparation with regard to their ability to remove tissue. They prepared the mesial canals of freshly extracted mandibular molars by one of the
following methods:

Group 1: nonserial preparation - A No. 10 or No. 15 file was passed to or just through the apical foramen. Each canal was enlarged at that working length to the size of a No. 30 or No. 35 file. In this group 10 canals were irrigated with water and 42 canals with 5.25% NaOCl.

Group 2: serial preparations - Working lengths were established as in Group 1. Each of the 50 canals was enlarged to a No. 30 or 35 at working length. The next larger file was then placed 1 mm short of the working length and worked at that level. Consecutively larger files were used to enlarge the canals at 1 mm increments from the apex. This was continued until a No. 60 file was used approximately 4 mm short of the apex. To complete the serial preparations, a No. 2 Gates-Glidden drill was then used in a up-and-down motion against the walls to a depth of 15 to 17 mm. Then a No. 3 Gates-Glidden drill was used in the same manner to a depth of 13 to 15 mm.
The prepared roots were then sectioned 1 mm, 3 mm, and 5 mm from the apex. The tissue content of each canal was evaluated and scored for each level.

The results showed that the serial preparations were significantly more effective than nonserial preparations in removal of tissue at all three levels studied. However, at the 1 mm level the serial preparations were judged to have tissue remaining in 14 of 39 or 36% of the canals.

McComb and Smith (1975) prepared recently extracted, single rooted human teeth "according to accepted clinical procedures." Canals resulting from the use of Kerr reamers, Kerr files, Kerr reamers and files used alternately, Hedstroem files, and Giromatic reamers. A variety of irrigants were used. The prepared canals were examined with a scanning electron microscope.

The results from this study indicate that most standard instrumentation techniques produce a canal wall that is smeared and often packed with debris which is not suitable for mechanical or chemical bonding of a root canal sealer. These results suggest that the currently accepted methods of root canal preparation are inadequate for the purposes of producing a clean canal.

A study designed to test the efficacy of different instruments and techniques in debriding and shaping root canals was reported by Mizrahi, et al., in 1975. The root canals of 30 freshly extracted single rooted human teeth were instrumented with either regular reamers, regular files, Hedstroem files, Giromatic broaches and Giromatic files and then irrigated with tap water. Instrumentation was considered complete when clean,
white shavings were obtained and when the canals felt smooth to the touch with the final instrument. The roots were split longitudinally, examined with the SEM, and evaluated on the basis of the quantity of debris and microorganisms remaining on the root canal walls.

The results indicated that use of a reamer and file in combination was the most effective means of cleaning the canal walls. They also found that one side of the canal generally seemed more thoroughly debrided than the other side. In some specimens the instruments did not touch both of the walls. Their findings agree with previously cited studies in that hand instrumentation in the conventional manner or with the use of an oscillating contra-angle, leaves significant amounts of tissue and debris in the root canal. The authors concluded that the criterion of stopping instrumentation when clean, white dentin filings are obtained may not be correct.

In 1976, Moodnik, et al., reported a study in which 25 freshly extracted, single-rooted human teeth were mechanically instrumented to the apex using a quarter-turn-pull technique. Twelve were instrumented with K-type files and 13 with Hedstroem files. Twenty specimens were irrigated with normal saline and five with 2.5% sodium hypochlorite. Instrumentation was carried three sizes beyond the point where clean, white dentin filings are seen.

The findings were somewhat different in this study in that they did not find one half of the root canal system better instrumented than the other half. The authors speculate that the reason for this difference is the difference in canal preparation techniques. In agreement with other
23,71,70 studies were their findings that almost all cases had a layer of sludge covering the instrumented surfaces. Also, it was observed that the walls of the root canals contained many irregularities that trap debris and harbor pulp tissue that current endodontic instruments are unable to remove. There was no difference between the results obtained with the K-type file and those obtained with the Hedstroem file.

Also in 1976, Walton published a study in which he evaluated debridement of root canals by estimating the percentage of walls that had actually been planed by files. The 91 canals evaluated were prepared in situ on teeth that were to be extracted for prosthetic or periodontal purposes. The degree of curvature of each canal was determined by Schneider's method. Canals were divided into two groups depending on whether their degree of curvature was greater or less than ten degrees. In all cases irrigation was carried out with 5% NaOCl. Working lengths of 1 to 2 mm from the radiographic apex were obtained. The canals were prepared in one of the following three ways:

1. Filed. Instruments were teased to working length, twisted until bound, and withdrawn by forcing them against the walls. This type of instrumentation was continued to at least two sizes beyond that which resulted in the length of the file being covered with clean dentin shavings and the walls felt smooth.

2. Reamed. Files were used in a reaming motion
at working length until they could be rotated freely. Instruments were not intentionally forced against the walls in a filing action when withdrawn. The criteria for completion of instrumentation were the same as for the filed teeth.

3. Step-back filed. The canal was prepared at working length to a size 25 or 30 by reaming action. From that point successively larger files were inserted to about 0.5 to 1 mm shorter lengths. This was continued until at least a No. 60 file was reached. When the step-back filing was begun, the files were rotated and withdrawn repeatedly while forcing the instruments against all walls in a filing motion.

Sections of the prepared canals were obtained either at 100\(\mu\)m intervals through the long axis of the root or at 300\(\mu\)m intervals in cross section. In order to evaluate whether the walls had been planed by the instruments, the percentage of walls in each section that had the predentin layer removed was estimated.

According to a statistical analysis of the results, step-back filing consistently, in all comparisons, planed more walls than did reaming or filing. The authors felt that this was true because larger instruments were used in most of the length of each canal. These larger
instruments were believed to cut more efficiently and were stiffer so they could be forced against the walls.

The poorest percentage of walls planed with all methods occurred in curved canals. Reaming and filing were the least effective. Both methods tended to remove tooth structure on the inside of the midportion of the curve and on the outside of the curve as it approached the apex. The walls opposite these areas were apparently untouched and contained layers of predentin and adherent cells and debris.

Step-back filing also tended to plane the outside of the apical portion of the curve, but did remove structure on the outside of the midportion of the canal. This resulted in a tapered and more completely debrided canal. Even though step-back filing scored the best of the three methods, it planed only 79% of the walls in curved canals.

The authors also found that the reamed and filed canals had a more uniform or round shape in cross section than did the step-back filing method. However, this greater uniformity was related to fewer walls planed.

They also found that preparing canals until the walls felt smooth and white dentin shavings were recovered were inaccurate determinants of total debridement.

Finally, the experimental method is useful in assessing the degree of debridement of various techniques and instruments.

Svec and Harrison in their study on irrigants prepared 40 single rooted human teeth with Kerr reamers and files. In each size a reamer
was followed by the same size file. Canals were enlarged to a size 35 or 60 depending on their original diameter. Irrigation was done with either NaOCl and H₂O₂ or saline solution. The prepared teeth were sectioned at the 1, 3, 5 mm levels from the anatomic apex.

The results showed that pulpal and dentinal debris were found in almost every section using either normal saline solution or the combination of NaOCl and H₂O₂.

Littman reported on a unique method of evaluating canal debridement. Ninety extracted human premolars were cleared of pulp tissue by soaking in NaOCl and then a radio-opaque medium was suctioned into each tooth. The teeth were prepared and the resulting preparations were x-rayed to see how much of the radio-opaque medium was still remaining on the canal walls. The teeth were prepared by one of the three methods following:

Method 1 - hand instrumentation to a size 50 apical preparation
Method 2 - Giromatic handpiece and Giromatic reamers to a size 50 apical preparation
Method 3 - hand instrumentation to an apical size 35 followed by a 1 mm reduction in working length for each succeeding instrument up to size 60.

Three different operators were used and each operator prepared canals by each of the three methods.
Irrigating solutions were intentionally omitted to evaluate only the effect of mechanical cleansing.

The study showed that no technique removed all the debris from the root canal system and that the three methods of instrumentation used are inadequate in total canal debridement. The author also noted that the performance of the operator appeared to have more significance than the preparation technique used.

This concludes the review of studies on root canal debridement by hand instrumentation. A brief review of the articles evaluating the mechanical handpieces designed for root canal preparation will now follow.

The Giromatic and similar handpieces were introduced to make endodontic procedures quick and easy. The Giromatic was not introduced into the United States until 1965.

In 1967, Frank published a study designed to present an endodontist's evaluation of shortcomings and merits of the Giromatic. He used the handpiece on countless extracted teeth and was unable to fracture a broach or to perforate lateral walls of canals. At this time the barbed broach was the only instrument available for use in the handpiece. He stated that a No. 10 file or reamer is still the instrument of choice for initial entrance into a canal. He concluded that the Giromatic can be of assistance in mechanical preparation of fine and curved canals; however, it is not to be considered the only tool for use in this practice.

Laws stated that, "preparing root canals remains time-consuming, and in the case of multirooted teeth, exhausting. Any aid which can
facilitate the routine mechanical preparation of root canals is worth consideration." He prepared 54 freshly extracted teeth with the Giromatic handpiece and broach. The prepared roots were split and examined under a dissecting microscope.

He found that the broaches would not reach the apex of every tooth nor would they remove irregularities in the canal walls. He also observed that holding the handpiece resulted in the loss of tactile sense, and penetration of curved canals was slow and difficult.

In the early 1970's, files and reamers were made available for operation in the Giromatic handpiece. These were necessary because the broaches were inadequate in removing dentin and shaping the canals.

Harty and Stock compared the preparation of mesial canals of mandibular molars with the Girofile to their preparation with a hand held file. They found very little difference in the time required to prepare the canals by the two systems.

Canals prepared with either mechanical handpieces or conventional hand instruments were injected with a silicone material in O'Connel and Brayton's study. The teeth were dissolved and the impressions studied. The canal preparations were graded on the criteria of shape, smoothness, elimination of morphologic aberrations and apical preparation. The conventional hand instrumentation proved superior in every category and required approximately the same amount of time as the automated instrumentation.

A study designed to compare serial preparations to Giromatic
preparations with regard to canal debridement was reported by Klayman and Brilliant. One hundred root canals in the mesial roots of extracted mandibular molars were prepared by either the Giromatic handpiece and Giro reamers or serial preparation with K-type files and Gates-Glidden burs. The serial preparation is the same as that described by Coffae and Brilliant. The prepared roots were sectioned at the 1 mm, 3 mm, and 5 mm levels from the apex.

At the 1 mm level, the serial preparation was statistically better at debriding the canal than the Giromatic. However, it is apparent from this study that currently used techniques of debriding root canals are inadequate. Serial preparation appears to be the best available alternative.

Mizrahi, et al., in their previously cited study found that the Giromatic broach was the poorest of the techniques evaluated in debridement of root canals.

Weine, et al., compared two means of hand instrumentation and two mechanical handpieces with regard to their effect on original canal shape. The four methods of canal instrumentation were reaming action, flaring and filing with flutes removed, Giromatic handpiece, and W & H handpiece. Preparations were done by all four methods on simulated curved canals in casting resin blocks. Also, curved canals in extracted teeth were prepared with the mechanical handpieces and radiographed after each size instrument was used.

The results indicated that the automated handpieces created the widest deviations from the original canal shape. The size of apical zips
was minimized most by flaring and removal of flutes. The only method that proved satisfactory with regard to final canal shape was the filed and flared preparation with flutes removed. Also, the speed of using the mechanical handpieces was definitely not greater than the methods of hand instrumentation. Preparation by reaming action was by far the fastest technique. The authors discouraged the exclusive use of the Giromatic handpiece in the preparation of curved canals.

In a study published by Brown, et al., in 1979, periapical leakage of canals prepared with the Giromatic handpiece and filled with RC-2B paste (Group A) was compared with that of canals prepared with conventional methods and filled with RC-2B (Group B) or with gutta-percha and sealer (Group C). Sixty freshly extracted single rooted human teeth were divided into the three groups.

The filled canals were tested for periapical leakage with an autoradiographic technique. The autoradiographs of Groups B and C showed a pattern of no leakage while Group A showed moderate leakage. The difference in the leakage patterns was probably due to the difference in technique as well as instrument used to prepare the root canals.
CHAPTER III

MATERIALS AND METHODS

Ideally, histologic studies such as this one would be done on human teeth, in situ. However, due to the difficulty in locating a sufficient number of suitable teeth that could be extracted at the completion of therapy and the virtual impossibility of obtaining patients willing to sit through root canal therapy on teeth scheduled for extraction, it is rarely possible to attain this ideal situation. It is then necessary to rely on animal experimentation with the attempt to simulate true clinical situations as closely as possible. The choice of a suitable animal is therefore important.

The difficulties in handling are minimized by the use of small animals such as rats, guinea pigs, and rabbits; however, they are not suitable for endodontic therapy due to the smallness of their dentition and difficult access. Thus, larger size animals must be used that have a dentition of comparable size to that of humans. The endodontic instruments used will then have an effect similar to their effect on human teeth. Also, the animals must be readily available at a reasonable cost and easily maintained. The dog satisfies these criteria and therefore, was the animal of choice for this study.

Barker and Lockett evaluated the dog and found it suitable for endodontic research. They recommended use of the mandibular 2nd, 3rd and 4th
premolars because they are readily accessible for all endodontic procedures and radiographing plus they are sufficiently wide to permit instrumentation with standard endodontic equipment. For this study it was decided that 2nd, 3rd and 4th mandibular pre-molars would be used as well as the mandibular 1st molar.

This study was performed on five adult Beagle dogs. The Beagle's qualities that make it desirable as an experimental dog are its medium size, even temperament, and adaptability to living in groups. Its greatest asset is its excellent disposition which makes any special handling or restraint unnecessary.

The dogs used were procured through the Animal Research Facility at the Loyola University Medical Center. Upon their arrival at the Research Facility the dogs were observed for a minimum of 10 days to insure that they were healthy. The dogs weighed between 10 and 12 kilograms (Kg). Each dog was identified by a numbered collar tag.

On the scheduled laboratory day, the dog was not fed in order to avoid complications while it was under general anesthesia. Prior to induction of the anesthetic solution the dog's front legs were partially shaved to expose the location of the large superficial veins.

General anesthesia was administered by intravenous injection of sodium pentobarbital.* The dosage was calculated on the basis of one cubic centimeter (cc) for each 2 Kg. of body weight. According to the manufacturer

*W.A. Butler Co., Columbus, Ohio
1.0 cc contained 65 milligrams of the barbiturate. Sodium pentabarbital is a long acting barbiturate whose principal action is depression of the central nervous system. Induction of anesthesia was immediate and uncomplicated in all cases. The dog was then secured to the operating table with tape. During the procedure, anesthesia was supplemented as necessary by injection of 1 cc doses into the same vein as the initial injection.

Immediately after induction of the general anesthesia, each dog was given a subcutaneous injection of 2 cc of atropine. The drug atropine sulfate is a cholinergic blocking agent. The main reason for administration of this drug was to inhibit salivary flow. In the small dose used, it also acts to stimulate the respiratory mechanism and nullify any bradycardia.

Preoperative radiographs were taken in order to evaluate the canal configuration and patency of the canals. The x-rays were taken with a portable, hand held unit (fig. 1). Lead lined gloves and apron were worn to protect the operator. The film packets were held in place by means of a hemostat and modeling clay as shown in figure 2. This allowed the procedure to be carried out by one person. All radiographs were developed in a portable dark box with rapid developing and fixing solutions. This allowed for film evaluation within sixty seconds and retakes when necessary.

The jaws were retracted by means of a spring loaded device that attached to the maxillary and mandibular cuspids on the opposite side of the mouth that was being instrumented. At each session work was limited to the 4 experimental teeth on one side. Due to the complete lack of salivary flow while the dogs were under anesthesia it was felt that a rubber dam was
not required. The teeth were isolated by buccal and lingual placement of 4 x 4 inch guaze pads.

Initial opening into the pulp chamber was made by reducing the entire crown until the mesial and distal pulp horns were exposed. This was done with a large heatless stone. At this point a number two round bur was used to remove the remainder of the chamber roof. Access openings were made very large in order to eliminate any tooth structure that may have interfered with direct access to the canal.

At this point the working length was determined by radiographs taken using small K-type files with silicone stops in place. (fig. 3 & 4) It was next determined for each canal what the largest file was that would reach full working length without any forcing or rotating. This was called the initial instrument.

The canals were then prepared by one of the two techniques of instrumentation being studied. All instrumentation was carried out with standardized 21-mm K-type files. The canals were irrigated with copious amounts of Clorox throughout the procedure. In each dog, all experimental teeth on one side were prepared by one technique while the teeth on the opposite side were instrumented by the other technique. Sides used for each technique were alternated in order to avoid incorporating any possible right vs. left side bias. All canals were prepared in two appointments as opposed to one appointment in order to more nearly simulate a typical clinical situation. At the end of each session the canals were dried with paper points, a dry cotton pellet was placed in the chamber and the canals were sealed with IRM. The starting and finishing time for each session were recorded. In addition
the following information was recorded for each session: session number, tag number of dog, side of mandible used, method of preparation, size of initial instrument and MAF.

A total of 40 bi-canaled teeth were prepared. Therefore 40 canals were instrumented by each technique. The two methods of canal preparation used were as follows:

Method I - Filing with flaring. After determination of the initial instrument, each canal was prepared sequentially through the next three file sizes to the full working length. This final file was designated the master apical file (MAF). After preparation with the MAF at working length was completed, the next three larger instruments were sequentially used a 1 mm, 2 mm, and 3 mm short of the full working length respectively. At this point the preparation was considered complete. All instruments were used with only a circumferential filing or rasping motion. No reaming action was used in the preparation of the teeth in this group.

Method II - Reaming with flaring. As in Method I these canals were prepared at full working length to three file sizes larger than the initial instrument size. After preparation with the MAF, the next three larger instruments were used at 1 mm, 2 mm, and 3 mm
short of the working length respectively. At this point preparation was considered complete. All instruments were inserted to the desired length, rotated approximately \( \frac{1}{4} \) turn and withdrawn. This was continued with each instrument until it could be rotated freely. As the files were withdrawn, no emphasis was placed on lateral rasping of the canal walls.

The dogs were sacrificed by IV injection of Beuthanasia-D.* The active ingredients of this preparation are pentobarbital sodium (195 mg/ml) and phenytoin sodium (25 mg/ml). The recommended dosage is 1 ml/2kg. This was done at the completion of final preparation appointment. The segments of mandible containing the experimental teeth were immediately removed and placed in formalin.

The specimens were kept in the formalin for 10 days and then the teeth were removed from the mandibles. This was done by grinding away the bone with a slow speed handpiece and round acrylic bur while flooding the field with water. When all the bone and soft tissue were removed from the teeth, the teeth were cut into a mesial and distal segment with a #699 bur in a high-speed handpiece. In this manner each root could be placed in a separate bottle of formalin and its identity maintained throughout the

*Burns-Biotec Laboratory, Oakland, California
study. Each root was labeled with a 4-digit and letter code as follows:

example label: 3-P2M

- 3 - session number - indicates method of instrumentation
- P - premolar (M - molar)
- 2 - 2nd
- M - mesial root (D - distal)

Each root was then wrapped in a 2 x 2 inch gauze along with its label. After the gauze was tied securely around each root, all of the roots were placed in one beaker containing 5% formic acid for the purpose of decalcification.

When the decalcification was completed, the apical delta common to dog teeth was trimmed from each root with a razor blade under a lighted magnifying lens. This trimming was done by the author and was stopped at the first sight of a central canal. At this time the temporary filling and cotton pellet were also removed.

The specimens were imbedded in paraffin and a 10 micron thick section was then taken perpendicular to the long axis of the canal at distances 1 mm, 2 mm, 3 mm, and 4 mm from the trimmed end of the root. The sections from each root were placed on a single slide and stained with hematoxylin and eosin.

The sections were then scored by three evaluators without their knowing which canals were prepared by filing or reaming. Two of the evaluators were second year endodontic graduate students and the third is a practicing endodontist and a member of the endodontic faculty at the Loyola University
School of Dentistry.

The following criteria were used to evaluate the preparation of the canal in each section:

a) Percentage of walls instrumented
b) Symmetry of the preparation
c) Amount of debris in canal

The sections were each scored on a scale of 1 to 5 with a score of 1 being the best and 5 the worst. The results were recorded and statistically analyzed by the two sample "t" test.
CHAPTER IV

RESULTS

The range of initial instrument sizes and the average working lengths for the various roots are given in Table I. Both the initial size of the canals and the length of the roots increased going from anterior to posterior.

The number of sections that exhibited debris in the canal was very small for both reamed and filed canals. Debris in the lumen of the canal was observed in only 6 of the 160 filed sections and 13 of the reamed sections. This debris was located at the 1 mm level in 5 of the 6 filed cases and in 11 of the 13 reamed sections. The remaining 3 sections that contained debris were at the 2 mm level. The debris was generally found in an area where the prepared canal deviated from the original canal. (Fig. 5) However, debris was not always present when the preparation deviated from the true canal. (Fig. 6)

It was observed in the filed sections that the preparation left the original canal a higher percentage of the time at the 4 mm level than at the levels closer to the apex. The reverse was true in the reamed canals. At the 1 mm level approximately the same number of filed preparations deviated from the true canal as did reamed sections. The "keyhole" type of preparation shown in figure 6 was present approximately twice as frequently in the filed specimens as in the reamed sections. This was due to the fact
that the filed canals showed this type of preparation at all levels whereas the reamed specimens showed the "keyhole" only at the 1 and 2 mm levels. At the 1 and 2 mm levels the "keyhole" was present equally in the filed and reamed sections. The only section that showed a migration of the prepared canal large enough to approach a "strip-type" perforation was at the 4 mm level of a filed premolar. Although large deviations occurred infrequently there were also very few canals prepared by either method that showed 100% of the walls instrumented in a section. There were no canals that presented sections at all four levels with 100% of the circumference instrumented.

The shape of the reamed canals was in general more nearly round than that of the filed canals. However, in the premolars the filed canals usually had smooth walls and in most cases it was very difficult to determine the method used by looking at a section under the microscope. However, in many of the molar canals, the indentations in the walls of the filed canals were apparent and reflected the rasping motion used. (Fig. 7)

Many of the sections exhibited a gray or translucent area adjacent to the canal lumen that radiated outward for a variable distance. (Fig. 8) These unstained areas appeared to follow individual dentinal tubules as they diverge from the canal.

With regard to the time spent on each technique, the average time for a filing session took 4.0 hours, whereas the reaming session required an average of 2 hours and 48 minutes.

**Statistical Evaluation of Results**

The Scores of the individual evaluators are given in Tables 2-4. This
data was used with the T-test for a statistical comparison of the reamed and filed canals. Examples of sections scored 1 through 5 are shown in figures 9 through 13.

For the first comparison all of the filing scores were compared as a single group to all of the reaming scores. The overall average score for the filed canals was 2.92 and the average for the reamed canals was 2.53. This difference was significant at the .05 level.

The next comparison was made by comparing the filing and reaming scores on a root-by-root basis. The average scores for each root are shown in Table 5. The average score for reaming was lower in all roots except P2M. The difference in scores was significant at the .05 level in all roots except P2M and P4D.

Table 6 shows the average scores for each level of preparation when all roots were combined under each technique. The score for reaming was lower at all four levels. The difference was not significant (P> .05) at the 1 mm level, but was statistically significant at the other three levels.

The final comparison made using the combined scores of all three evaluators compared each filed root to its reamed counterpart at each of the four levels. The average scores are shown in Table 7. Table 8 indicates where the differences in Table 7 are significant and which method was scored better. Filing was scored significantly lower at the 1 mm level of root P2M. Reaming scored lower at the 3 mm level in roots P3M and P3D and at the 4 mm level in root P4M. Note that the "Total" column of Table 8 summarizes the statistical significance of the data shown in Table 5.
Next the scores of each individual evaluator were analyzed in a manner similar to the analysis of the combined scores. The overall average score for evaluators 1, 2, and 3 were 2.87, 2.73, and 2.51 respectively. Overall, evaluators 1 and 3 scored reaming significantly lower than filing while evaluator 3 found no statistically significant difference between the two methods.

Tables 8, 9, and 10 show where each evaluator's scores showed significant (P< .05) differences between reaming and filing and which method scored better.
Table I: Initial Instrument Sizes and Average Working Lengths

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<th>Average Length</th>
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## Table 3

Scores from Evaluator #2

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</tbody>
</table>
### Table 4
Scores from Evaluator #3

<table>
<thead>
<tr>
<th>Root</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>2 mm</td>
</tr>
<tr>
<td>P2M</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>P2D</td>
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<td>3</td>
</tr>
<tr>
<td>P3M</td>
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<td>3</td>
</tr>
<tr>
<td>P3D</td>
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<td>3</td>
</tr>
<tr>
<td>P4M</td>
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<td>3</td>
</tr>
<tr>
<td>P4D</td>
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<td>3</td>
</tr>
<tr>
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<td>2</td>
</tr>
<tr>
<td>M1D</td>
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<td>3</td>
</tr>
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<td>1</td>
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<tr>
<td>P3D</td>
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<td>2</td>
</tr>
<tr>
<td>P4M</td>
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<td>3</td>
</tr>
<tr>
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<td>1</td>
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<tr>
<td>P3D</td>
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</tr>
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</tr>
<tr>
<td>P4D</td>
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</tr>
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<td>3</td>
</tr>
<tr>
<td>P2D</td>
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<td>3</td>
</tr>
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</tr>
<tr>
<td>P3D</td>
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</tr>
<tr>
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</tr>
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</table>
Table 5: Average Score for Each Root Combining All Levels and All Evaluators

<table>
<thead>
<tr>
<th>Root</th>
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<th>Reaming</th>
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</thead>
<tbody>
<tr>
<td>P2M</td>
<td>2.51</td>
<td>2.73</td>
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<tr>
<td>P2D</td>
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<tr>
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<tr>
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Table 6: Average Scores at each Level Combining All Roots and All Evaluators

<table>
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<th>Level</th>
<th>Filing</th>
<th>Reaming</th>
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</thead>
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<tr>
<td>1 mm</td>
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</tr>
<tr>
<td>2 mm</td>
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<td>2.87</td>
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<td>4 mm</td>
<td>3.04</td>
<td>2.53</td>
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</table>
Table 7: Average Scores at each Level in each Root for Filing and Reaming

<table>
<thead>
<tr>
<th>Root</th>
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<th>3 mm</th>
<th>4 mm</th>
<th>1 mm</th>
<th>2 mm</th>
<th>3 mm</th>
<th>4 mm</th>
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<tr>
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<td>2.9</td>
<td>3.0</td>
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<td>2.9</td>
<td>2.4</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>P3M</td>
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<td>2.4</td>
<td>3.0</td>
<td>3.1</td>
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<td>3.0</td>
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<td>3.1</td>
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<td>3.6</td>
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<td>3.3</td>
<td>2.7</td>
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<td>2.4</td>
<td>2.4</td>
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<td>2.3</td>
<td>2.4</td>
<td>2.3</td>
<td>1.9</td>
<td>2.1</td>
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</table>

Table 8: Statistically Significantly Differences Between Reaming and Filing Scores

<table>
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<th>KEY: F = filing significantly lower score</th>
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<tbody>
<tr>
<td>P2M</td>
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<td>--</td>
<td>--</td>
<td>R</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>P3M</td>
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<td>R</td>
<td>--</td>
<td>R</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>P3D</td>
<td>--</td>
<td>--</td>
<td>R</td>
<td>--</td>
<td>R</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>P4M</td>
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<td>--</td>
<td>--</td>
<td>R</td>
<td>R</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>P4D</td>
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<td>--</td>
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<td>--</td>
<td>--</td>
<td>--</td>
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</tr>
<tr>
<td>M1M</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>M1D</td>
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</tr>
</tbody>
</table>

KEY: F = filing significantly lower score

-- = no significant difference between reaming and filing

R = reaming significantly lower score
Table 9: Evaluator #1 - Significant Differences Between Reaming and Filing Scores

<table>
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<th>3 mm</th>
<th>4 mm</th>
<th>Total</th>
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<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>P2D</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>R</td>
</tr>
<tr>
<td>P3M</td>
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<td>--</td>
<td>--</td>
</tr>
<tr>
<td>P3D</td>
<td>--</td>
<td>R</td>
<td>R</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>P4M</td>
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<td>--</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>P4D</td>
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<td>--</td>
<td>--</td>
</tr>
<tr>
<td>M1M</td>
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<td>--</td>
</tr>
<tr>
<td>M1D</td>
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<td>--</td>
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</table>

Table 10: Evaluator #2 - Significant Differences Between Reaming and Filing Scores

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<th>Total</th>
</tr>
</thead>
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<td>F</td>
</tr>
<tr>
<td>P2D</td>
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</tr>
<tr>
<td>P3M</td>
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</tr>
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<td>P3D</td>
<td>--</td>
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</tr>
<tr>
<td>P4M</td>
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</tr>
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</tr>
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<td>--</td>
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</tr>
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<td>M1D</td>
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</tbody>
</table>

KEY:  
F = filing significantly lower score  
-- = no significant difference between reaming and filing  
R = reaming significantly lower score
**Table 11: Evaluator #3 - Significant Differences Between Reaming and Filing Scores**

<table>
<thead>
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<th>3 mm</th>
<th>4 mm</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2M</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>P2D</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>P3M</td>
<td>--</td>
<td>--</td>
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<td>--</td>
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</tr>
<tr>
<td>P3D</td>
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<td>--</td>
<td>--</td>
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</tr>
<tr>
<td>P4M</td>
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<td>--</td>
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<td>R</td>
</tr>
<tr>
<td>P4D</td>
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</tr>
<tr>
<td>M1M</td>
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<td>--</td>
<td>R</td>
</tr>
<tr>
<td>M1D</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>R</td>
</tr>
</tbody>
</table>

**KEY:**

- \( F \) = filing significantly lower score
- -- = no significant difference between reaming and filing
- \( R \) = reaming significantly lower score
DISCUSSION

There are many factors which must be taken into consideration when comparing techniques of root canal preparation. These factors include the initial and final canal size, shape, and curvature; and the final degree of canal debridement.

Evaluating the initial canal factors is extremely important when using experimental teeth other than human teeth. Without this information, application of the results to the true clinical situation would be impossible. Considering the teeth used in this study, it should be kept in mind that the canals are essentially straight and round. The only human teeth that consistently fit into this category are the maxillary central incisors. The initial instrument size ranged from 10 to 100 so that the full spectrum of canal width was covered.

For the purpose of evaluating the prepared canal, studies have been designed to look at the effect of preparation on canal shape and curvature or the debridement of the canal. The ideal study would, however, show both the degree of canal debridement and the amount that the preparation deviated from the original canal. It was felt that the technique used in this study for examining the prepared canals most nearly approximated the ideal. Under the microscope (100x), the cross-sectional specimens could be examined with regard to debridement and deviation of the preparation from the true canal.

Both methods of preparation did an excellent job of removing debris
at the 2, 3, and 4 mm level. Although not proven by this study, the complete lack of debris at the more cervical levels could be attributed to the flaring of the canals. The flaring allows for better flushing of the irrigants plus the use of larger instruments within the canal. Coffae and Brilliant found that serial preparations removed debris at the 1, 3, 5 mm level significantly better than non-serial preparations. They, however, found that 36% of their serial preparations still contained tissue at the 1 mm level. That percentage is much higher than that found in this study. The reason they had a higher percentage of canals with tissue debris is probably due to the fact that they prepared mesial canals of human mandibular molars which are curved and much more difficult to prepare than the straight canals used in this study.

Other studies done on extracted human teeth have reported finding that the walls of the prepared canals were smeared and packed with debris. In the present study, that finding was not made. However, the studies that did find the smeared walls used the scanning electron microscope to examine canals which had been split longitudinally. That method of examination may be more appropriate for locating this smeared layer.

When evaluating the preparation of any canal, it is generally agreed that the apical 1 to 2 mm are the most critical. This is where the seal should be obtained when the canal is obturated. As found in Ingles' study, lack of apical seal was the leading cause of endodontic failures. Crump, Malooley, and Russin noted that canals that are unclean at the 1 mm level are difficult if not impossible to seal. Unfortunately, it is at this
level that debris or deviations of the prepared canal from the true canal are to be found. In this study, debris was found primarily at the 1 mm level. Debris was found at this level in 3% of the filed teeth and 9% of the reamed teeth. These teeth represent the simplest endodontic treatment situation (i.e. straight canals with easy access). It could be theorized that in curved canals the above percentages would be higher.

With regard to evaluating the change in canal shape, examining cross-sections does not give the overall picture that comparing pre- and post-treatment radiographs would. However, the cross-sectional specimens do show at a specific level how the preparation has stayed within or deviated from the path of the original canal. In the present study, the observation of concentric rings of secondary dentin within the canal was a very useful way of locating the boundaries of the original canal. Figure 5 demonstrates these rings and also shows how the preparation in this case has migrated to one side of the canal.

It is obvious that a preparation that does not enlarge a canal in all directions but deviates to one side will not adequately debride the entire canal. This phenomena has been observed in other studies, and was found to occur frequently in this study also. Through microscopic examination it was judged that there were significant deviations to one side of the original canal in 68 of the filed sections and 49 of the reamed sections.

These numbers make it appear that reaming would be a much better method for preparing this type of canal. However, when the number of
deviations is compared level by level it is seen that at the 1 mm level there are essentially (16 reamed; 17 filed) the same number by each method. As stated earlier this is the most critical level for attaining a good seal assuring the success of the treatment.

The statistical analysis of the scores given to each of the sections by three independent evaluators agrees with the above findings.

When the overall scores for filing were compared to reaming, reaming was scored significantly lower. Also, when the two techniques were compared on a root by root basis, reaming scored significantly lower in 5 of the 8 roots with the remaining 3 roots showing no significant difference between the two techniques. However, when the scores were evaluated level by level, which is the more meaningful and clinically relevant way to compare these techniques, the results were somewhat different.

When filing was compared to reaming at the 1 mm level using the scores of all the roots together, there was no statistically significant difference between the two methods. At the 2 mm, 3 mm, and 4 mm levels reaming was scored significantly lower.

Table 8 shows a further breakdown of the combined scoring of all three evaluators. The two techniques were compared at each level on a root by root basis. This analysis was done in order to determine if the difference in initial size of the canal affected the efficiency of either technique. It can be seen that at the 1 mm and 2 mm levels there was no significant difference between the two techniques in any root except root P2M. In this root, filing scored significantly lower than reaming at the 1 mm.
level. The initial size of the canal did not make any difference when comparing the two techniques in this study.

The author found it quite surprising that straight canals which were circumferentially filed would show preparations that migrated to one side of the canal. During preparation extreme care was taken to insure that the canals were filed around their complete circumferences. Apparently, however, the orifice was the area being circumferentially filed while in many cases more apical regions were being instrumented on only some of the walls. A close examination of the pre-treatment or initial file radiographs reveals a constriction at the orifice of the canals. As shown in the mesial root of the first molar in Figure 14, this constriction could force an instrument to one side of the canal near the apex. Elimination of this constriction prior to the major portion of canal instrumentation would allow the operator to have more control over the files in the apical portion of the canal.

This situation is analgous to human anterior teeth. If these teeth are instrumented with inadequate access openings, interferences from either the incisal portion of the crown or a lingual portion of the roof of the chamber will make it impossible to control the direction of the instrument in the apical third of the canal. These findings would tend to support the use of preflaring as a means of eliminating cervical interferences before more apical canal preparation is carried out.

The choice of the initial instrument was done very carefully in order to select the largest possible file. It was felt that this was especially
critical for the reamed canals. Whereas the instrument in the circumfer-
entially canals is directed against the walls by the operator, the prepara-
tion of the reamed canals depends solely on the size of the instrument
relative to the size of the canal. In this study the canals were prepared
to three sizes larger than the initial instrument. If too small of an
initial file were selected in the reamed canals, little or no preparation
would occur by the time the master apical file is reached.

The criteria used to determine when canal preparation is complete is
somewhat arbitrary. Several studies have shown that stopping preparation
when "clean, white dentin shavings" are being removed from the canal is not
a valid method for determining the adequacy of the preparation.

Moodnik even prepared the canals in his study 3 sizes beyond the point
where clean, white dentin filings were seen. He still found that almost
all of the canals were inadequately prepared. The present study has
shown that carrying the preparation 3 sizes past that of the initial in-
strument is no guarantee that the canal is completely debrided. By observ-
ing the deviations the preparations took from the original canal, it can
be surmised that use of even larger and consequently stiffer instruments
would only increase these deviations and not effect a better debridement
of the true canal.

It can be inferred from the results of this study that the satisfac-
tory cleansing of a canal depends on using a technique which will not
deviate from the path of the original canal and will, therefore enlarge
the canal equally around its circumference. Therefore, the size of the

MAF takes on secondary importance to the method of preparation used.

It is believed by the author that the unstained areas radiating from lumen of many of the canals were caused by the action of the Clorox on the soft tissue in the dentinal tubules. Eosin stains cytoplasm and intercellular substances. Therefore, it appears that the NaOCl has either removed these materials or altered their staining characteristics. Until it is more fully understood, the clinical implications of this phenomenon cannot be fully understood. If, in fact, the NaOCl did cleanse the dentinal tubules of soft tissue, it would definitely be a beneficial effect with regard to endodontic therapy. Further research needs to be done in this area.

There was an appreciable difference in the amount of time required to prepare the canals by each technique. The results of this study are in agreement with Weine's study which found reaming to be the fastest technique when comparing three preparation techniques. Although time required should not be the primary factor considered in selecting a technique it is an important consideration in a clinical situation. With all other factors being equal it would be logical to select the faster of two methods.

In the present study reaming was scored equal to or better than filing according to the criteria previously listed. It was also the faster of the two methods. However, before selecting this technique over filing, the factor of instrument breakage should be considered. The probability of separating an instrument in a canal by either of the two techniques and the effect of such an occurrence on the prognosis of the case should be taken into consideration.

Instrument breakage occurs primarily through twisting files when
they are bound in the canal. This occurs primarily with instruments smaller than a size 35. The risk of separating an endodontic file within a canal by the use of a rasping motion is negligible for all instrument sizes. A segment of a file lodged in a canal is in most cases extremely difficult if not impossible to remove. This can adversely affect the prognosis of the case due to the fact that the broken instrument prevents further debridement and adequate sealing of the canal.

Considering the above information along with the data collected in this study, the author feels that reaming is the technique of choice when preparing straight canals that have an initial instrument size greater than 35. For canals smaller than this, filing is recommended.

The author feels that in future studies of this type histologic sections of control teeth with unprepared canals be made. These would act as a basis or point of reference in evaluating the prepared canals. Also, it would be advantageous to mark all roots in such a way that the buccal, lingual, mesial, and distal directions would be apparent in the final histologic section. This would aid in determining possible causes for the prepared canal deviating from the true canal.

Further study needs to be done comparing these preparation techniques in human teeth with curved canals. The results of such a study would be applicable to a much greater percentage of clinical cases than the results of this study. Also, the effect of preflaring canals on the apical preparation should be investigated.
Eighty root canals in five Beagle dogs were prepared by standard endodontic procedures. Using sodium hypochlorite as an irrigant, the canals were instrumented with K-type files by one of the following techniques.

1. Forty canals were prepared by the use of a circumferential filing or rasping motion.

2. Forty canals were prepared by the use of a reaming or \( \frac{1}{4} \)-turn and withdraw technique, with no emphasis placed on lateral filing as the instrument was withdrawn.

Canals prepared by both methods were enlarged at full working length to three sizes larger than the initial instrument. They were then flared by progressively using each of the next three larger instruments 1.0 mm. short of the preceding instrument. All canals were prepared in two appointments.

Histologic sections were then made perpendicular to the long axis of the canal at levels of 1 mm., 2 mm., 3 mm., and 4 mm. from the apical end of the canal. These sections were evaluated and scored in a blind fashion by three evaluators using the following criteria:

1. Percentage of walls instrumented

2. Amount of debris present within the canal

3. Symmetry of the prepared canal
The sections were scored on a scale of 1 to 5, with 1 being the best score and 5 the worst.

A statistical analysis of the results was done and there was no significant difference between the scores of the two techniques at the 1 mm. level. At the 2 mm., 3 mm., and 4 mm. levels, reaming was scored significantly better than filing.

Both techniques were very effective in removing debris from the canals; although, filing proved slightly more effective in that respect. The techniques showed an approximately equal tendency to have the prepared canal deviate from the true canal at the 1 mm. level.
REFERENCES


Fig 1. Radiographic technique with hand-held X-ray unit.

Fig 2. Film held in place with hemostat and modeling clay for working length radiograph.
Fig. 3. Files in place with directional silicone stops for length control.

Fig 4. Radiograph showing files in place for working length determination.
Fig 5. Histologic section, 1 mm. level, showing debris in the canal and the Preparation deviating from the original canal. ("keyhole" type preparation). (orig. mag. X 63)

Fig 6. Histologic section, 3 mm. level, showing prepared canal deviating from the original canal. (orig. mag. X 63)
Fig 7. Histologic section, 1 mm. level, showing a filed molar canal with grooved walls due to rasping action of instrument. (orig. mag. X 63)

Fig 8. Histologic section, 1 mm. level, showing unstained area radiating from the prepared canal and an unprepared canal. (orig. mag. X 30)
Fig 9. Histologic section, 2 mm. level, demonstrating a canal scored as a "1". (orig. mag. X 63)

Fig 10. Histologic section, 4 mm. level, demonstrating a canal scored as a "2". (orig. mag. X 63)
Fig 11. Histologic section, 1 mm. level, demonstrating a canal scored as a "3". (orig. mag. X 63)

Fig 12. A histologic section, 4 mm. level, demonstrating a canal scored as a "4". (orig. mag. X 63)
Fig 13. A histologic section, 1 mm. level, demonstrating a canal scored as a "5". (orig. mag. X 63)

Fig 14. Radiograph showing constriction at the orifice of the mesial canal of the first molar.
The thesis submitted by Terry L. Kippa has been read and approved by the following committee:

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science in Oral Biology.

4/21/61
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